

Testing of a Plastic Melt Waste Compactor Designed for Human Space Exploration Missions

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ABSTRACT

Significant progress has been made at NASA Ames Research Center in the development of a heat melt compaction device called the Plastic Melt Waste Compactor (PMWC). The PMWC was designed to process wet and dry wastes generated on human space exploration missions. The wastes have a plastic content typically greater than twenty percent. The PMWC removes the water from the waste, reduces the volume, and encapsulates it by melting the plastic constituent of the waste. The PMWC is capable of large volume reductions. The final product is compacted waste disk that is easy to manage and requires minimal crew handling. This paper describes the results of tests conducted using the PMWC with a wet and dry waste composite that was representative of the waste types expected to be encountered on long duration human space exploration missions.

INTRODUCTION

The PMWC development effort was a result of a systems analysis conducted at NASA Ames research center in 2001 to assess the current state of the art life support waste management technologies. The intention of the study was to determine if the existing and

proposed waste processing concepts were optimized for the current human space exploration mission scenarios or whether there were areas for improvement. It was discovered that the volume of trash accumulated on space missions, such as a Mars Transit, would be a problem. The trash models of past human space missions such as Space Shuttle, MIR, Skylab, and International Space Station contained a significant percentage of plastic and it was expected that future long duration exploration missions would be similar [1]. The resource recovery potential from plastic was considered low when compared with the energy required to break the plastic down into the basic elements. Compaction was viewed as a simplistic and robust solution to manage the high volume trash. Standard compaction methods suffered from issues such as trash spring-back after the compression load is removed and compaction bag puncture and leakage.

A process termed compress melt compaction was discovered that offered large trash volume reductions by preventing spring-back after compression. This method also eliminated the issue of trash bag tearing and leakage. The compress melt compaction method of waste processing was major source of inspiration for the development of the PMWC.

Originally the PMWC was designed with a primary focus on trash volume reduction. The PMWC was based off of hardware developed for the U.S. Navy. U.S. Navy shipboard operations generated large amounts of plastic rich trash. To ameliorate the trash problem, the NAVY solicited the development of a device called the Compress Melt Unit (CMU). The CMU was large, heavy, and had high energy consumption. A space application of this technology would need to focus on low energy consumption, operation in micro-gravity, water recovery, and operation in closed loop spacecraft environment. The compress melt technology looked promising for applications to human space exploration missions due to its ability to achieve large volume reductions and simplify crew handling and storage of the final trash product. The PMWC developed at NASA Ames Research center placed a focus on operation in a micro-gravity environment, hardware mass reduction, and reduced energy consumption. Water recovery was considered in the design of the PMWC but minimal attention was paid to this aspect of the PMWC design due to lack of funding.

The first PMWC was designed with an emphasis on operations in a micro-gravity environment. The PMWC was designed prior to the current lunar exploration effort and was intended for a Mars transit mission with the ability to be adapted for use on the Martian surface. The PMWC was designed from data gained from breadboard unit compress melt tests conducted in 2003 [2].

In 2008 the focus was the use of the PMWC to recover water from trash. Since the PMWC project was not originally funded to assess water recovery, modifications to the hardware were required to accomplish this task. The modifications to the hardware included the incorporation of water recovery equipment and modifications to the hardware to prevent pooling resulting from operation in a hypo-gravity environment.

MAIN SECTION

HARDWARE DESCRIPTION - The PMWC is a compaction device that raises the temperature of the waste to the melting point of the plastic constituent then compresses the waste. The plastic is bonded to the other trash components during compaction producing a hard disc with the consistency of solid plastic. The final product does not need a bag or container to constrain the different components of the trash which are bonded to the plastic component of the waste. During the heating process the water in the trash is driven off for water recovery.

The current PMWC was designed to function primarily in a micro-gravity environment. A major part of the design focus was the reduction of forces required for crew input and extraction of the trash from the PMWC. Without the proper design considerations for operation in a micro-gravity environment, the crew would have extreme difficulty operating the device without the use of body

constraints, I.E. foot constraints. Designing the PMWC for automation plays a major role in the reduction and elimination of certain force and torque inducing procedures required to remove trash from the PMWC.

The PMWC was designed to allow automation of the all processes except trash input and the final trash removal step. A major part of the design was the processed waste disk removal portion of the PMWC. The processed waste disk needs to be separated from the face of the piston ram. To do this manually in micro-gravity environment would induce forces and torques that would be difficult to constrain. Due to typical spacecraft size, space, and hardware orientation constraints, it may not be possible to incorporate the necessary foot or body constraints required for manual disk removal. The disk removal portion of the PMWC automates the disk separation from the piston ram and allows a simple, near zero-force removal of the disk from the PMWC. Other features incorporated into the design for automation were the piston constraint locking mechanism and the high flow zero-differential pressure two way seal gate valve.

When fully automated the PMWC operator would only need to fill the trash input receiving area with trash, shut the door, then push the processing button. All thermal, compaction, water removal, and disk/piston separation processes would be automated. This includes compaction, heating to dry the trash and melt the plastic, sterilization if required, cooling of the processed waste disk, separation of the disk from the piston ram, and resetting the hardware to the initial trash receiving mode at the end of the process. When the process is completed an indicator light would tell the operator that the processed trash disk is ready to be removed from the PMWC. Once the operator removes the disk from the PMWC, the hardware resets itself and is ready to receive more trash. To summarize, only three steps are required for nominal operation of a fully automated PMWC: trash input, pressing the process initiation button and finally the removal of the processed waste disk from the PMWC. The operator does not need to be present during any of the automated processes.

The current PMWC has a mass of approximately 60 kg, a volume of 0.38 m³, and has a total heater capacity of 1.4 kW with a heater flux of 1.55 Watts/cm². In comparison, the NAVY CMU specifications state that the CMU uses 50 amps at 440 VAC which indicates a total power of 22 kW which is approximately sixteen times higher than the PMWC. It is not known if the NAVY CMU actually operates at 22 kW as indicated. The PMWC waste processing chamber has a volume of 5.3 liters and a diameter of 20.3 cm. The PMWC is capable of producing compaction gage pressures as high as 5.1 bar generating a compaction force of 16.5 kN. The current hardware was not mass optimized but is still roughly fourteen times lighter than the NAVY CMU. The PMWC is shown in figure 1 below.

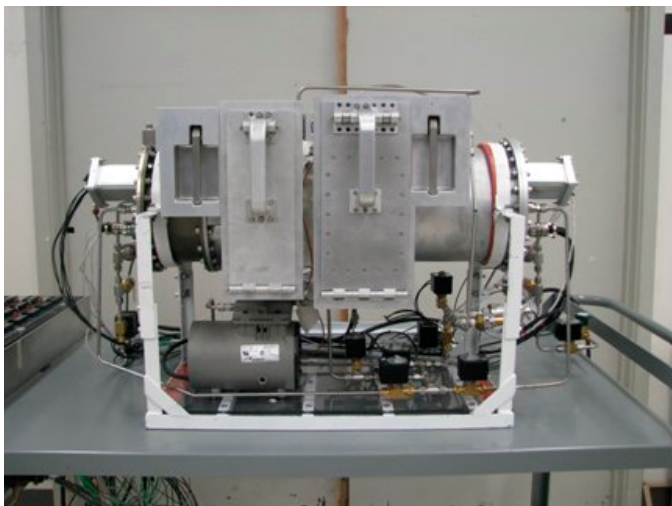


Figure 1. The PMWC

When the PMWC was designed, the primary function was volume reduction and no funding was provided for the incorporation of water recovery equipment. Some minor consideration for water recovery was given in the design of the PMWC for operation in a micro-gravity environment. In the micro-gravity environment the water and water vapor would be drawn into a water recovery device using airflow via a pump, fan, or compressor. Modifications were necessary to allow the PMWC to operate in a hypo-gravity environment to prevent pooling of water in locations of the ventilation chamber that would not normally occur in micro-gravity.

The only automated portion of the current PMWC is the temperature control. The heater temperatures are controlled by adjustable micro-controllers. The compressor, valve operation, and initial power on of heaters are all controlled through switches located on a central control box.

It was discovered during testing that the average power usage of the PMWC showed a 40% to 50% duty cycle indicating that the PMWC heaters could be reduced to less than 0.7 kW by reducing the heater flux by half.

TESTS AND RESULTS – A description of the waste model, test methods, conditions, and test results is discussed below.

Waste Model - The waste model used for tests in the PMWC was based on a study performed by K. Wignarajah at NASA Ames Research Center. The waste model compares with the waste model quantity and water percentages for the space shuttle missions described in the waste subsystem section 4.3 of the BVAD [1]. The waste model was comprised of polyethylene bags, plastic syringes, polypropylene, aluminum cans, tortillas, celery stalks, turkey breast lunch meat, metalized plastic drink pouches that consisted of aluminum laminated to polyethylene and polyethylene terephthalate, free water in the drink

pouches, non-alcoholic sanitary wipes, cotton rags, duct tape, and latex gloves.

The percentage of water in the trash was approximately 30% by mass. 17% of the water came from the food items, 35% from drink pouches and what was absorbed into the cotton wash cloths, and 48% of the water came from the non-alcoholic sanitary wipes. The percentage of plastic in the trash was 32% by mass. Drying tests were performed on the wastes in a drying oven to determine the water percentage of the individual components. The components were sanitary wipes, celery stalks, turkey breast lunch meat, and tortillas which were found to contain 71%, 95%, 52%, and 17% moisture content by mass respectively.

The nominal batch size used for the tests was 0.5 kg but the batch sizes were eventually doubled to 1.0 kg to assess the ability of the PMWC to handle larger quantities of trash. The 0.5 kg and 1.0 kg tests used the same constituent percentages. The batch sizes were based on the current PMWC capacity which is not considered full scale. The current PMWC can process the trash generated daily by a four person crew in as little as 6.5 cycles per day based on a total waste generation rate of 8.45 kg per day. The average density of the trash when manually packed into the PMWC chamber was observed to range from 90 to 95 kg/m³. The volume of manually compacted trash generated for a four person crew per day would be approximately 90 liters.

The waste was not shredded or pre-processed before being placed into the PMWC with the exception of the food items which were made to fit into plastic sandwich bags. Whole rags, aluminum drink cans, and plastic bags were placed directly into the PMWC waste processing chamber.

Test Conditions - The experiments were conducted in a laboratory with an average temperature of 21°C. The primary temperature settings that were investigated for the plastic melt process were based on standard moist heat and dry heat sterilization temperatures. The use of standard sterilization temperatures was considered with the assumption that the PMWC may eventually be required to sterilize the waste. For the 2008 PMWC activities only water recovery, volume reduction and equipment function were assessed at the specified sterilization temperatures. There is currently no funding for sterilization testing and no efforts were made to analyze the waste for microbial activity.

The temperature used in most experiments was 132°C which is a standard moist heat sterilization temperature. 132°C is above the minimum melting temperature of most types of polyethylene, the main plastic constituent of the waste. The highest temperature used was 180°C which is on the upper end of standard dry heat sterilization processes. Waste processing temperatures ranging from 20 to 90°C were also tested to assess

vacuum drying of the trash below the melting point of the polyethylene.

The tests were performed with waste chamber pressures as low as 124 mbar but the average waste chamber pressure during processing ranged between 190 mbar to 230 mbar. The compaction pressures tested ranged from approximately 1.0 to 5.1 bars. Air was pulled into the waste processing chamber from the ambient environment to allow flow for catalytic oxidization testing. The flow rate upstream of the inlet flow restriction valve ranged between 0.8 lpm to 1.3 lpm for the majority of tests.

For a typical test the heating, compaction, and waste chamber vacuum was initiated simultaneously. For most tests the heaters were allowed to ramp up to the set-point temperature at full power (without a controlled or reduced ramp rate). The average time to reach a set point temperature of 132°C for a 0.5 kg waste load was approximately 5.5 minutes. The average time to reach 132°C for a double size load of 1.0 kg was approximately 7.5 minutes. The thermal soak time for the standard 0.5 kg load tests was 60 minutes with the 1.0 kg double load tests being 100 minutes.

The aforementioned temperatures represent the surface temperature of the trash at the point of contact with the aluminum compaction piston heat transfer surface. The RTD temperature sensors used to control the heaters were behind the 6.35 mm aluminum piston face next to the heating element with a small insulation separator between the heater and the RTD. It was not possible to put temperature sensors in direct contact with the waste during processing without performing a significant modification to the hardware therefore no attempts were made to directly monitor the trash temperature during processing. A test was performed without waste to observe the difference in temperature between the temperature sensor next to the heater and an adhesive thermocouple on the piston surface that would be exposed to the trash. It was observed that the difference between the temperature sensor next to the heater and the piston surface exposed to the trash was less than 1°C.

Cooling was tested with both a forced air fan and no fan. The ventilation system of the PMWC has a Papst type 5606 S axial fan that capable of generating 4,500 lpm at one standard atmosphere, zero delta pressure. The pressure sensors on the PMWC are set to read to the tenth decimal place and are not sensitive enough to evaluate the level of vacuum induced in the chamber as a result of the fan therefore the flow-rate through the ventilation system as a result of the fan is not currently known. The differences between observed cooling times with and without the fan were relatively small. The processed waste disks were usually cooled to less than 60°C before being removed. The time to cool to 60°C was approximately 50 minutes for the 0.5 kg and 60 minutes for the 1.0 kg double load tests. The

temperatures indicated represent the processed waste product surface temperatures at the time of removal and it is assumed that the core temperatures of the waste were increasingly higher than the surface temperatures with respect to increased trash quantity.

Results - The average water removal was 93%. Up to 100% water removal from the waste was achieved with as high as 99% percent water collected in the condensate collection flask.

The trash volume reduction averaged 90% from an initial volume of 5.3 liters and an initial density ranging from 90 to 95 kg/m³. A typical processed waste disk is shown in figure 2 below.



Figure 2. Waste disk produced in the PMWC

The average power to process the 0.5 kg and 1.0 kg trash samples was 0.63 kW with a specific power of 1.29 kW/kg-trash and 0.64 kW with is specific power of 0.65 kW/kg-trash respectively. The difference between the specific power to heat the 0.5 kg and 1.0 kg trash samples indicate that the majority of energy is being used to heat the hardware and is also being lost to the environment via convection. The maximum heater power was 1.4 kW during the initial ramp up period which averaged 5.5 minutes for the 0.5 kg load and 7.5 minutes for the 1.0 kg load. The average power after the set-point temperature was reached was slightly less than 0.40 kW. The power consumption of 0.40 kW is assumed to be primarily due to convection losses to the surroundings with a small percentage of the energy being used to evaporate the remainder of the water in the trash.

A single test was conducted at a temperature of 180°C. The specific energy consumption was higher than tests performed at lower temperatures. The water recovery rate was similar to the lower temperature tests but with